Fermilab
ES&H Section

RADIATION PHYSICS NOTE 142

Long Term Trends in Radiation Exposures at Fermilab

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Introduction

The purpose of this short note is to report on an examination of trends in personnel radiation dose equivalent at Fermilab since the commencement of accelerator operations in the 1972-1973 time frame. In a long-term trend, doses measured at Fermilab have declined dramatically over the years. This is true for both the total effective dose equivalent summed over all monitored personnel and for individual doses. This trend is likely due to the level of importance given to radiation protection, part of a broader emphasis on environment, safety, and health that has matured along with the Laboratory. Furthermore, a noticeable correlation of enhanced radiation exposures with periods of fixed target operations is seen. Future operations at higher beam intensities are likely to continue to present challenges in dose control.

The Data

The data presented here were obtained directly from the records of the ES&H Section, including annual summaries provided to the Department of Energy and its predecessor agencies. In each plot, the raw data is plotted as a bar chart while a 3-year running average is superimposed as a line graph. The abscissa on all graphs is the calendar year. Thus, the results will differ in detail from those reported in recent years for the DOE TEDE Performance Measure which has been defined for time intervals connected with the fiscal year that have varied from year to year. At the outset it should be noted that the predominant source of radiation exposure at Fermilab is due to gamma radiation from accelerator and beamline components. Prompt radiation is of much less importance.

The results in Figure 1 are the most dramatic, but the general downward trends in the others are obvious, too. To obtain the values in Figure 2, the TEDE value is divided by the number of people who received a measurable exposure (see Figure 3). Normalizing by this rather than by the number of badges issued excludes the many “zero” exposures received by those who are badged for “precautionary” reasons. There are some uncertainties in the counting of temporary dosimetry badges, particularly in the earlier years. Thus, the actual values may be somewhat higher due to some people wearing multiple badges while performing radiological work during a given year. This effect is not expected to be large. In Figure 2, the trend in the average dose equivalent received per exposed individual is especially revealing. In the early years 3000 and even 4000 mrem annual doses to individuals were quite common while for 2002, the highest value recorded was 450 mrem and only 26 people received more than 100 mrem.[1] This is typical of recent experience. The least dramatic trend is that shown in Figure 3, which is essentially a "head count". As in Figure 2, particularly in the early years there may be some duplicative counting of exposed persons resulting from the use of temporary badges.

Discussion

Individual radiation exposures were quite high, by present standards, during early Fermilab operations. However TEDEs of comparable magnitudes were also reported at other large accelerators at that time. In reviewing available documentation, some efforts to address these and other safety problems as early as 1975 are clearly evident. In the documentation available, and perhaps in the memories of our senior staff, the firm leadership of Directors R. R. Wilson and L. M. Lederman are quite evident in addressing this and other safety issues. In 1977 Wilson formally appointed a Senior Safety Officer and a Senior Radiation Safety Officer. Also in 1977 an ad hoc committee led by J. Appel performed an internal review of the Radiation Physics Group, then located in the Accelerator Division. In late 1977 a Director-appointed review committee led by L. Voyvodic recommended, among other actions, that an independent "Safety Department" be established. As a result of these deliberations, the Safety Section (now the ES&H Section) was created in July 1978. Also in this epoch, the functions of what is now known as the Laboratory Safety Committee and its subcommittees, including the Radiation Safety Subcommittee, and the roles and responsibilities of line management were more clearly articulated. Mechanisms for safety review of new projects were established. About that time, the line organizations, principally the former Research and Accelerator Divisions, began to hire specialists to deal with radiation safety matters (both professionals and technicians), and shortly thereafter staff additions in other areas of safety were made. In 1979, Lederman strongly reaffirmed the line safety management philosophy of Fermilab first set forth by Wilson in essentially the same form it exists today. This philosophy as stated is remarkably consisted with what we now call "integrated safety management".

While there are some year-to-year fluctuations in the dosimetry results, they are not all that large considering that there have been whole years where the only major activity at the Laboratory was civil construction while there have been others where physics research program operations dominated. Improvements in control of radiological hazards are seen to be gradual, but steady in nature. In addition to the programmatic improvements mentioned in the previous paragraph, improved accelerator operations in the late 1970's undoubtedly helped by reducing the need for "hot job" repairs or the levels of residual radioactivity encountered in those tasks.

[1] 100 mrem in a year is roughly equivalent to everyone's *external* dose equivalent due to cosmic ray and terrestrial backgrounds not including *internal* exposure to radon in buildings. This value serves as a *de facto* annual limit on dose equivalent that can be delivered to members of the public as a result of human activities.

Significant improvement is correlated with the advent of the Tevatron in 1983. With its superconducting magnets, the Tevatron is far less tolerant of beam loss than was the former Main Ring and in fixed target mode handled less beam power (proton energy times intensity)[2]. The intolerance to beam loss motivated improvements in beam diagnostics and methods of beam loss control that had an additional benefit of reducing levels of induced radioactivity in all parts of the accelerators beamlines. Since that time, gradual improvements continue to be made.

From 1983 through 1991, accelerator operations consisted of alternate operation of Tevatron collider and fixed target experimental physics programs, usually with some of each occurring in a given calendar year. This correlation with Tevatron fixed target operations should be examined more closely. Appel, et al. described the Fermilab Tevatron fixed target program[3]. In their report they listed the experiments by designated Experiment Number that were operational during each fixed target run. One can use this number, cautiously, as a figure of merit to describe the scope of a given run since, to some degree, this value is correlated with the number of target stations and secondary beamlines used. Since 1987 or so, periods in which Tevatron fixed target operations were not conducted were dominated by Tevatron collider runs along with accelerator maintenance and development, and some civil construction, "Caution" needs to be employed in the use of these data due to the wide variation in the scope of accelerator operations associated with each experiment ranging from immense high intensity targetry to relatively small scale tests. In this report, no adjustment is made for duplicate numbers assigned to essentially the same experiment for program planning purposes. With these *caveats*, Table 1 lists the approximate run period for each fixed target run along with the number of experiments recorded for that period. The dates of operations are *approximate* ones inferred from a time-line found in the cited reference.

Table 1 Numbers of Approved Experiments Per Tevatron fixed target Operational Period

Approximate Tevatron fixed target Running Period	Number of fixed target Experiments
October 1983 – February 1984	5
April 1984 – June 1984	6
January 1985 – August 1985	12
June 1987 – January 1988	17
February 1990 – August 1990	14
July 1991 – January 1992	12
June 1996 – August 1997	8
June 1999 – January 2000	3

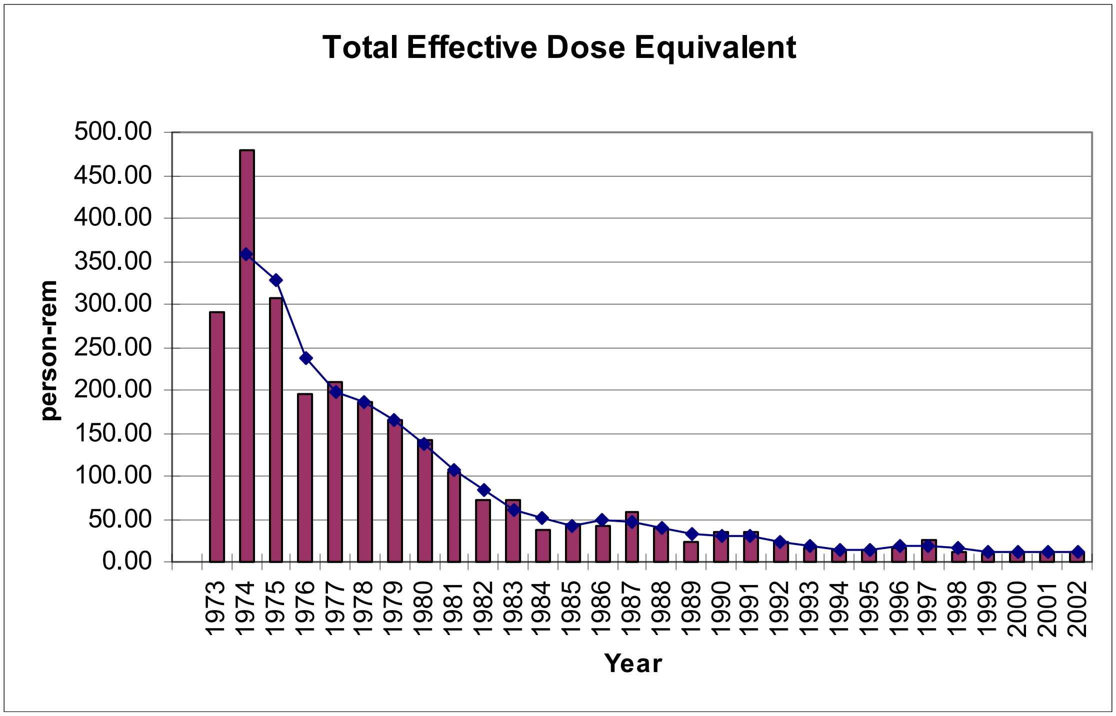
[2] Many features of the radiation fields at high energy accelerators, while only weakly dependent upon energy, are strongly correlated with the beam power.
[3] J. A. Appel, C. N. Brown, P. S. Cooper, and H. B. White, "Proceedings of the Symposium in Celebration of the fixed target Program with the Tevatron," June 2, 2000.

It is seen that in except for the first two Tevatron fixed target runs in 1983-1984, which could be said to have been a bit "developmental" in nature, there is a mild qualitative correlation of increased radiation doses with fixed target operational periods. Further, the largest fixed target runs, as measured by the numbers of experiments taking data, seem to be related to the more obvious increases in doses received. To this author, this result is not surprising. During Tevatron collider operations conducted during this period, only one target station, the Antiproton Target, was normally operational. This target station is built for a single purpose; to produce antiprotons. It is generally regarded as being exceedingly well-designed from the dose control standpoint having features made straightforward by its single purpose. A number of target stations designed to supply diverse types of secondary particles at a variety of energies were used in the fixed target program. Often, these target stations needed to be reconfigured periodically to meet experimental requirements and unforeseen repairs had to be accommodated. These tasks all involved significant radiological work. While dose control and reliability features were carefully considered during their construction, the nature of their operation presented significant dose control challenges. There were also as many as 12 of them operational simultaneously at the height of the program. Some "dose overhead per target station" is plausible.

Conclusions

As beam intensities are enhanced to match programmatic requirements, continued diligence will be needed to continue to control radiation exposures effectively. Increased production of antiprotons required to meet the unique scientific goals of the Tevatron Collider program requires enhanced beam intensities. Also, the resumption of fixed target operations to address important scientific questions using conventional, not superconducting, magnets in the Linac, Booster, and Main Injector (e.g., MiniBooNE, Switchyard 120, and NuMI) pose significant challenges to the control of radiation exposures that are understood. It is likely that dose control in fixed target beamlines will continue to pose challenges. The control of beam losses is currently the subject of a great deal of ongoing theoretical and experimental accelerator physics studies. This work is motivated by the need to enhance beam intensities while improving reliability. Fortunately, these objectives dovetail with keeping radiation exposures as low as reasonably achievable (ALARA).

The staff of Fermilab will continue to give high importance to the control of radiation exposures while optimizing the performance of the scientific research program.



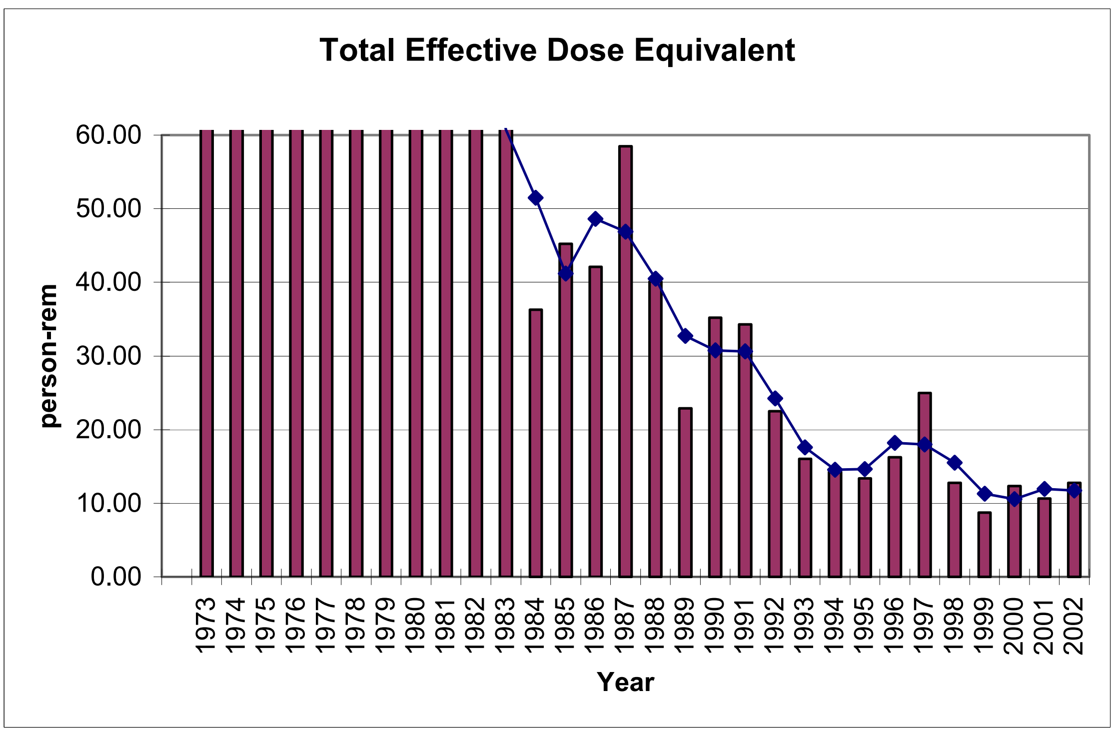


Figure 1. The total effective dose equivalent (TEDE) in units of person-rem is plotted by calendar year. The bottom frame plots the same data as does the top frame, but is scaled to better exhibit recent results.

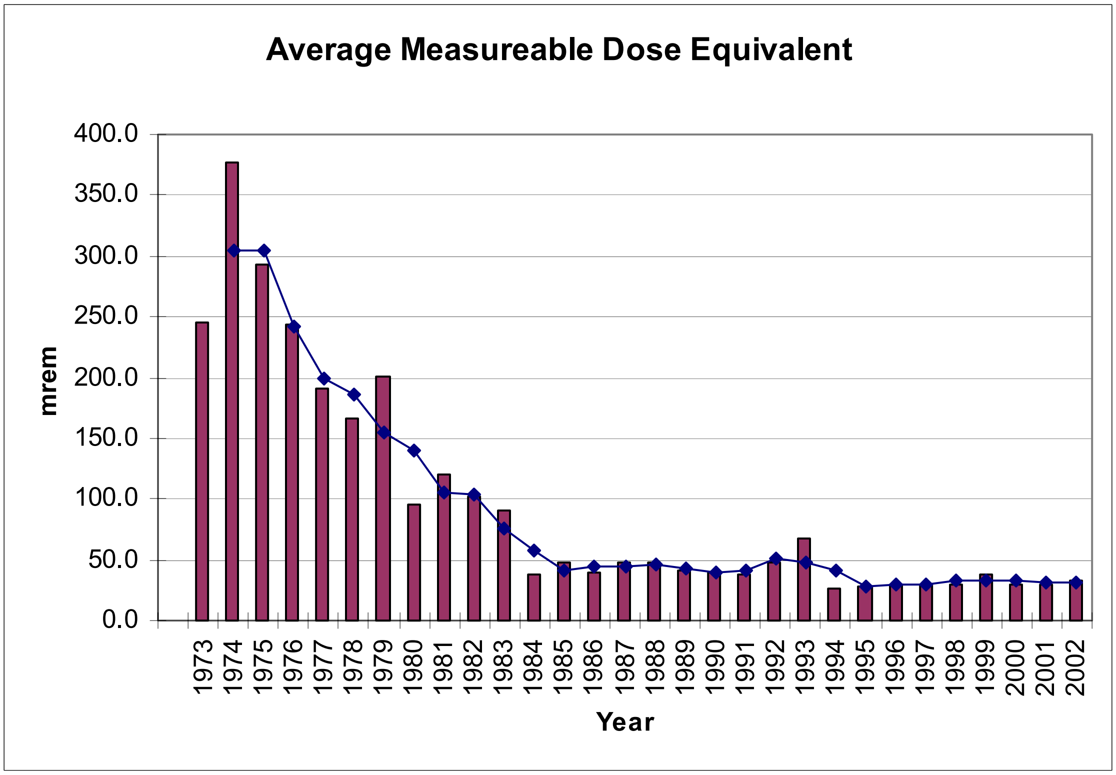


Figure 2. The average measureable dose equivalent to individuals is plotted by calendar year. Personnel receiving nonmeasureable dose equivalent are not included.

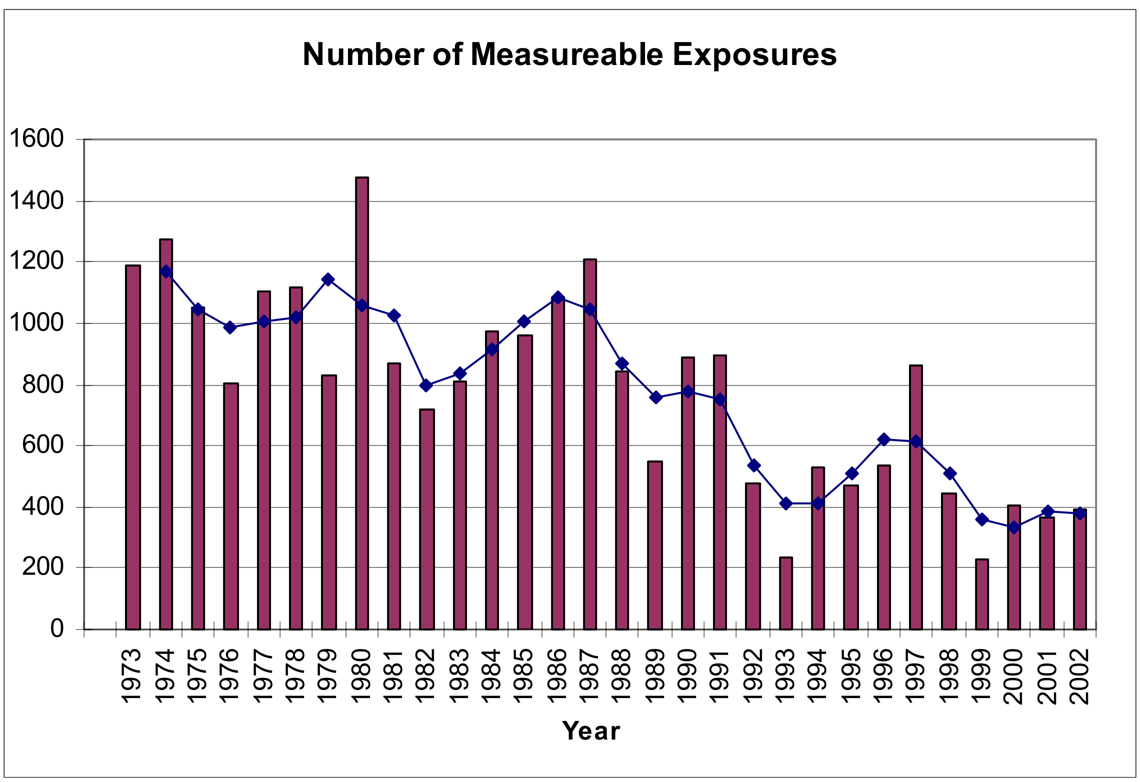


Figure 3. The number of measurable exposures is plotted by calendar year.